A STUDY OF PIPE LEAK SOURCE LOCATION USING SINGLE CHANNEL ACOUSTIC EMISSION SYSTEM

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ABSTRACT

This project discusses the study of a new approach of Acoustic Emission Testing (AET) for pipe leak detection. The conventional practice of AET usually use at least two Acoustic Emission (AE) sensors to detect the leak location which is expensive. Therefore, this project was carried out to overcome this problem by using only one AE sensor to detect leak. The objective of this project is to develop an algorithm by using acoustic emission technique to detect pipe's leak. The project design for this project is by using a test rig which is equipped by a one meter leaked galvanized iron (GI) pipe with size ¾ inch diameter, a hydraulic bench, acoustic emission sensor, acoustic emission node and acoustic emission software. The RMS value of AE wave were recorded and analyzed. An average value of RMS was determined from those four reading at each points. The result shows that the leak at pipe can be determined from the inclination or slope of the graph average vs distance. The leak is located when the slope of the graph, -0.0008 ± 0.0006. The results of the experiment prove that using one acoustic emission sensor can detect the leak location at pipeline.

ABSTRAK

Projek ini membincangkan kajian keatas ujikaji pancaran akustik (AET) untuk mengesan lokasi kebocoran pada paip. Kaedah konvensional AET menggunakan paling kurang dua sensor pancaran akustik (AE) yang tinggi kosnya. Oleh itu, projek ini telah dijalankan untuk mengatasi masalah ini dengan menggunakan satu pengesan. Objektif projek ini adalah untuk membangunkan satu algoritma dengan menggunakan AET untuk mengesan kebocoran pada paip. Projek ini menggunakan satu paip besi bergalvani dengan kebocoran, satu bangku hidrolik, satu sensor AE, satu node AE dan perisian AE. Nilai RMS daripada gelombang AE dirakam dan dianalisis dan satu nilai purata RMS telah dikenalpasti. Hasil menunjukkan kebocoran paip boleh dikenalpasti daripada cerun graf. Kebocoran terletak pada kecerunan graf, -0.0008 ± 0.0006. Hasil kajian ekperimen ini menunjukkan AET mampu untuk mengenalpasti kebocoran pada paip.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Technology of pipeline has been developed in order to increase the potential and ability of this type of transportation. Nowadays, pipelines have become a regular practice to transfer the material from raw source to the end user. Due to this economic transportation, pipelines become a major role in the petroleum industry because this method is safe, reliable and constant flow of crude oil, natural gas and petroleum products.

Leak can occur from small holes caused by corrosion up to catastrophic pipeline failure due to manmade damage or natural causes such as earthquake (Huebler, 2000). Because of this matter the development of pipe leak monitoring was introduced and research will keep running to improve the system from time to time. If the surface exposed, the location of the leak can be determined by visual technique. But if the pipe is coated or buried, the location of the leak or crack is difficult to be determined by visual technique.

Therefore, there are several non-destructive testing (NDT) technique has been applied for this application to detect earliest leaking condition. Three conventional techniques are generally used including visual inspection using penetrate material, hydrostatic testing and ultrasonic testing (Heubler, 2000). These methods provide inadequate sensitivity and time consuming. For that reason, acoustic emission (AE) technique incorporate with hydrostatic testing has been proposed to replaced conventional technique is that is provides sufficient sensitivity to detect a micro leaking propagations in solid material.

1.2 PROBLEM STATEMENT

A conventional acoustic emission technique that been practiced nowadays is by using two sensors to determine the location of leak at pipeline. Cost for sensor usually high. Instead by using two acoustic emission sensors, use a sensor to locate leak at pipe should be reduce the cost on sensor.

1.3 OBJECTIVE

The objective of this project is to develop an algorithm with acoustic emission technique which can use to locate the leak at pipeline by using only one acoustic emission sensor. The second objective of this project is to use clustering method to cluster signal properties at different location.

1.4 SCOPE OF THE STUDY

For this project, the study will base on the development of pipe leak detection using single channel acoustic emission technique. Two pipes are used where one is the pipe with leak and the other one is a pipe without leak. The pipe that used in this project is about one meter.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Piping was used widely for domestic or industry. It seems pipe line method was cheaper than other transportation method such as shipping. Sometimes pipe can break or crack. This phenomenon can cause losses to the company. So, it’s good to know the weakness of the pipe during early stage which is initial cracking stage whereas the initial crack process. There are several factors that contribute to the pipe failure such as soil loading, ground surface loading (e.g. due to traffic) and as a result of temperature changes. (Atkinson et al, 2002)

Any big crack obviously can detect using sight. Crack that occurs at atoms level is not really visible. Nowadays there was technique that can be used to detect any defect on the pipeline. Non-Destructive Technique was most popular technique that been used by industry. Transportation for petroleum was suggested to use pipeline system as primary option (Mandaleev, 1863).

Several large industries were recognizing the trend of NDT’s trend and its potential market For example, the establishment of a Quality Technology Center in Cincinnati by the General Electric (GE) Co, in which over 100 people are working to develop advanced NDT techniques including X-radiography, tomography, ultrasonic, eddy currents, optical-visual testing and infrared. These techniques are now being useful to aerospace examination problems but it seems clear that GE would not start such a procedure except it recognized the potential for wider applications. Nonetheless these technique mentioned before, acoustic emission (AE) technique also included one of the NDT (Berger, 1988).

2.2 CRACK CLASSIFICATION

Failure of the pipe was determined by many factors. The factors that usually lead to the failure such as natural disaster or artificial. Crack is usually contributed to the failure of the pipelines. According to Heubler, he said that there are three types of cracks which is crack that need to fix during 24 to 48 hours, crack that need to fix in 30 days and crack that did not need any on the spot repair, but need to be observe (Heubler, 2000).

By interpreting the acoustic signature of the event, it is possible to detect a defect event along the pipeline. The problem is to identify acoustic emission signature of a defect from the background noise such as pimping noise, flow turbulence noise, valve actuation and other influences that may appear.

2.2.1 Fatigue Crack

Fatigue and fracture tests of piping models with flaws in the inner surface were carried out to investigate the fatigue crack growth, coalescence of multiple cracks and fracture behavior. (Shibata K. et al, 1981) In figure 2.1, Persistent slip bands PSBs are areas that rise above (extrusion) or fall below (intrusion) the surface of the component due to movement of material along slip planes. This leaves tiny steps in the surface that serve as stress risers where fatigue cracks can initiate. A crack at the edge of a PSB is shown in the image below taken with a scanning electron microscope (SEM).

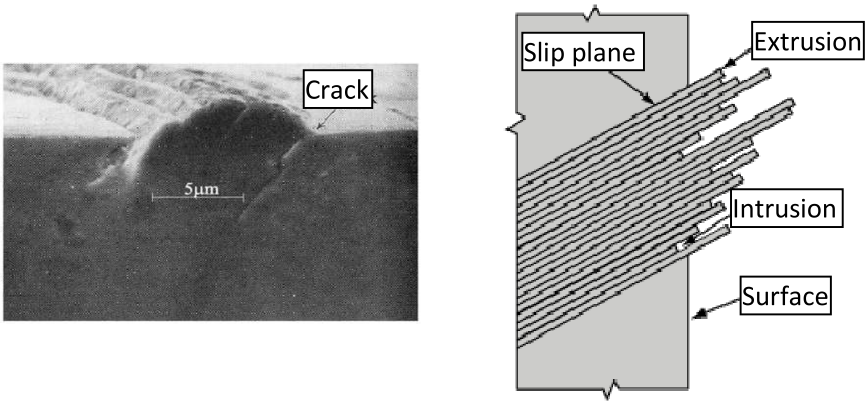

Figure 2.1: A crack at the edge of a persistent slip bands (PSB) is shown in the image above taken with a scanning electron microscope (SEM)

Source: Anastos et al (2001)

PSB are areas that rise above (extrusion) or fall below (intrusion) the surface of the component due to movement of material along slip planes. This leaves tiny steps in the surface that serve as stress risers where fatigue cracks can initiate. A fatigue crack is formed as the result of localized plastic deformation during cyclic straining. Due to the pressure cycling and physical deformation of the pipe, the crack will start and grow constantly.

2.2.2 Hook Crack

This type of crack occurs at the welded part. It will be significant after certain time due to the material's fatigue properties. Thus, it cannot be detected right after it was produced by manufacturer. Figure 2.2 is a photomicrograph of a hook crack. It measures 0.186 inches (4.7 mm) deep with a part of that measurement being associated as a possible fatigue crack.

Hook crack or upturned fiber flaw is defined in API Bulletin 5TL as, "Metal separations resulting from imperfections at the edge of the plate or skelp, parallel to the surface, which turn toward the inside diameter or outside diameter pipe surface when the edges are upset during welding." (Meade, 2006)

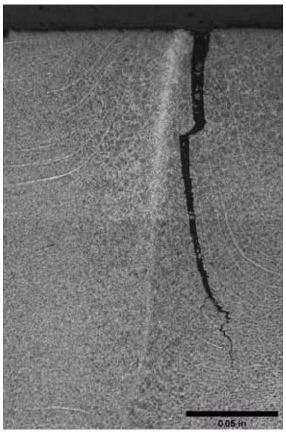

Figure 2.2: Hook Crack

Source: Meade R. (2006)

2.2.3 Stress Corrosion Cracking (SCC)

According to the ISO definition "stress corrosion cracking is cracking due to a process involving conjoint corrosion and straining of a metal due to residual or applied stresses". Usually, typical metals are exposed to the corrosion. The mechanism of SCC is shown as a simple representation in Figure 2.3. Not to include with noble metal like gold and platinum. For cracking under influence of ammonia, they were called 'season cracking' and the crack occurs in strong alkali called 'caustic cracking'. (Arup and Parkins RN, 2000)

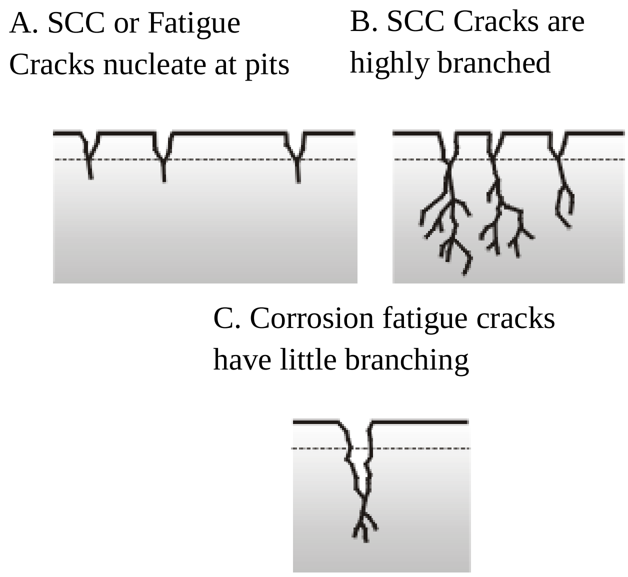

Figure 2.3: Schematic view of Stress Corrosion Cracking (SCC) and corrosion fatigue cracking

Source: Pearce (2000)

2.3 ACOUSTIC EMISSION

Acoustic emission is a transient elastic waves that come from local internal micro displacement in material. Acoustic emission appears in two different signal shapes, which are shown in Figure 2.4 relative to their origins. The signal of acoustic emission appears in two types as below. (Runow, 1985)

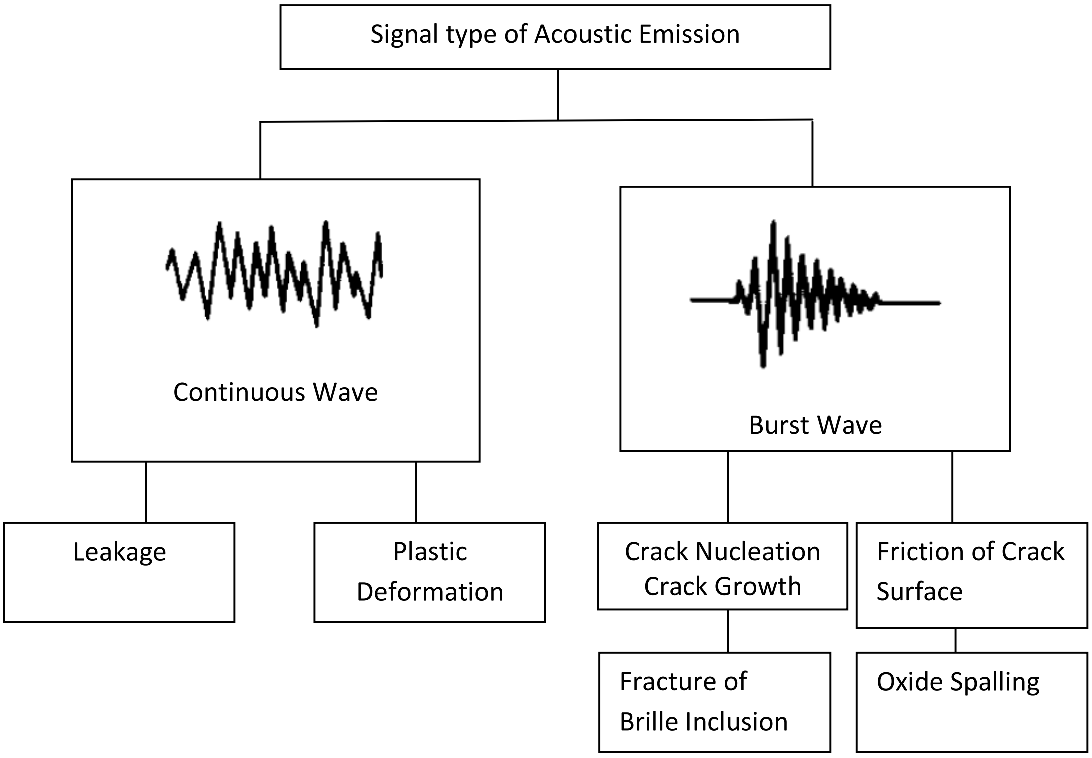

Figure 2.4: Signal types of acoustic emission related to their mode of origin

Source: Runow (1985)

Basically, a material produces defect when apply with certain stress. As the result, that material will release energy and as a source of elastic waves. Then, this wave will propagate through material or medium. Some of this wave will be reflected or convert into a surface wave which is propagate along the boundary. (Sachse et al, 1991)

2.3.1 Burst Wave

By using an appropriate device, surface wave can be detected by placing the device very close to the surface's material. This device can produce an electrical pulse due to detected waves and this electrical pulse can be analyzed. Figure 2.5 shows the characteristic of a simple AE waveform. There were some parameters included within AE wave. Acoustic emission can be detected by using piezoelectric sensor and passed to preamplifier.

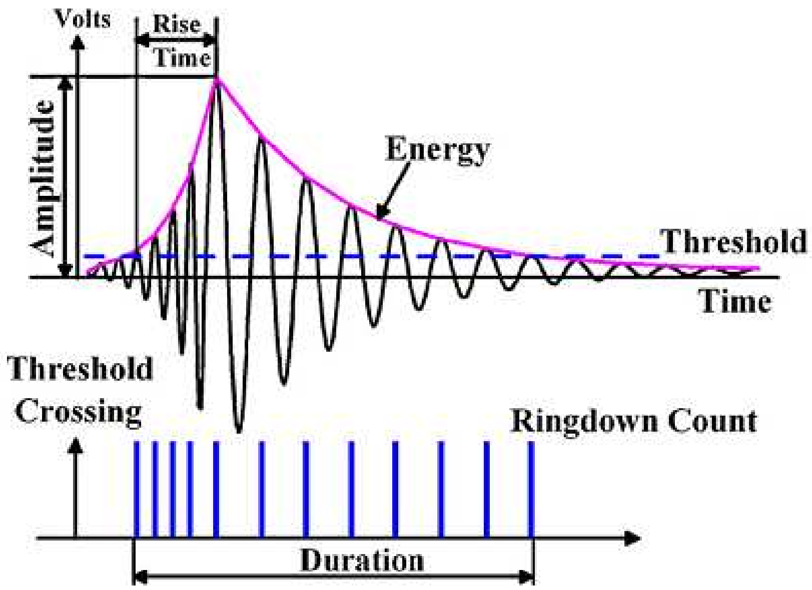

Figure 2.5: Method of extracting AE parameters

Source: Ai Q. et al (2010)

2.3.2 Acoustic Emission Parameter

The parameters for AE wave that can be obtained from this wave is event, ring down count (RDC), peak amplitude, rise time, event duration, energy and signal level (RMS voltage). Rise time is defined as time required from the first wave that crossed with threshold voltage until the maximum amplitude. Decay time is time used from the maximum amplitude until the last wave that crossed with the threshold voltage. Generally, the AE wave generated during deformation have rise time values about l-3 µs. The rise time is an indication of the time to reach peak value of the energy released. (Moorthy, 1996)

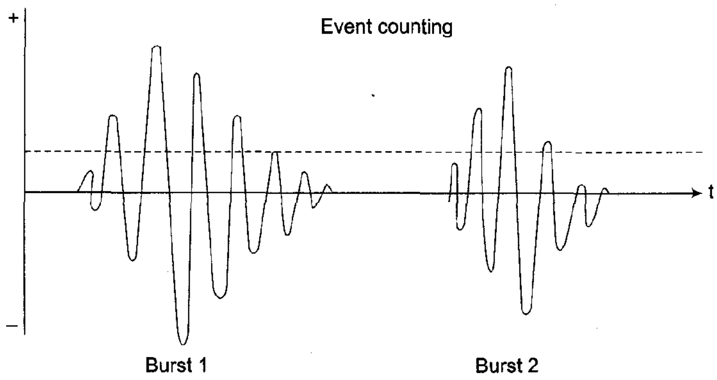

Figure 2.6: Example of event counting.

Source: Kalyanasundaram et al (1990)

A microstructure displacement that produces elastic waves in the material called an AE event. The time between first wave and the last wave which is crossing with threshold voltage. Meanwhile event count is how many waves that crossing the threshold voltage for each burst.

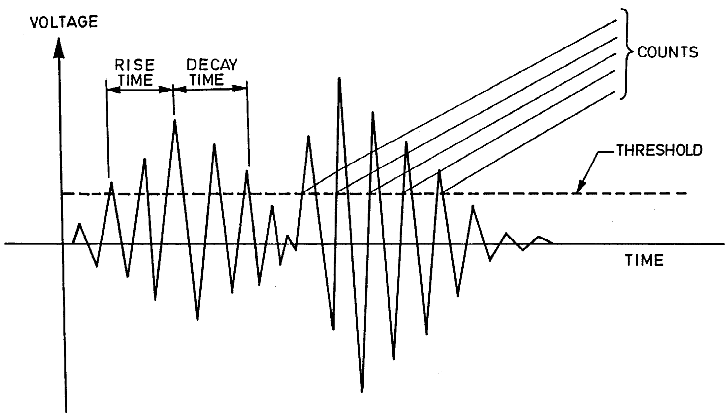

Figure 2.7: Typical characteristics of a simple AE wave form.

Source: Mathews and Shunmugam (1998)

2.3.3 Signal Analysis

AE signal can be describe by a series of wave strains of the same pattern, but with different of the amplitudes and time of waves occur by this expression

$$x(t) = \sum_i v_i g(t - t_i), \quad i = \cdots, -1,0,1,2, \ldots \tag{2.1}$$

Where v_i and t_i are the amplitude and time of occurrence, respectively, for the i^{th} burst and g(t) is the assumed wavefront of a single burst. It is often assumed that g(t) is a damped, sinusoidal oscillation which can be expressed by the function **(**Mitrakovie, 1985)

$$g(t) = \begin{cases} e^{-t/\tau} sin2\pi f_o t, & t > 0 \\ 0, & t < 0 \end{cases} \tag{2.2}$$

Where f_o is the resonant frequency of the tranducer, and τ is the characteristic decay time. f_o is determined by the resonant frequency of the transducer and τ is defined by the total damping of the corresponding ultrasonic component in the system under test. An equivalent Q factor can then be defined by the formula

$$Q = \pi f_o \tau \tag{2.3}$$

Experimentally, practical burst amplitudes different over a wide range. Three orders of magnitude are usually enough for the classification of the incident. Investigations have shown that the amplitude distribution is valid for a variety of situations. Where V_o is the smallest amplitude that can be detected, and b is a characteristic parameter of the amplitude distribution when the probability of high amplitude burst increase, b decreases.

$$P_r\{v > V\} \begin{cases} \left(\frac{V}{V_o}\right)^{-b}, & V \geq V_o \\ 1 & V < V_o \end{cases} \tag{2.4}$$

The probability density can be defined as

$$p(V) = P_r\{V \leq v < V + dV\} = \frac{d}{dV}\{1 - P_r\{v > V\}\} \tag{2.5}$$

With the condition

$$\int_0^{+\infty} p(V)dV = 1 \tag{2.6}$$

From the (2.4) and (2.5)

$$p(V) = \begin{cases} \frac{b}{V_o}\left(\frac{V}{V_o}\right)^{-(b+1)} & , \ V \geq V_o \\ 0 & , \ V < V_o \end{cases} \tag{2.7}$$

During the process of cracking, smaller value of b can be obtained when large-amplitude burst are more repeated.

2.3.4 Acoustic Emission's System

In figure 2.8, it shows the acoustic emission's system included with a sensor, preamplifier, filter, amplifier, display, storage equipment. Typically, systems contain a sensor (transducer), preamplifier, filter, and amplifier, along with measurement, display, and storage equipment (e.g. oscilloscopes, voltmeters, and personal computers).

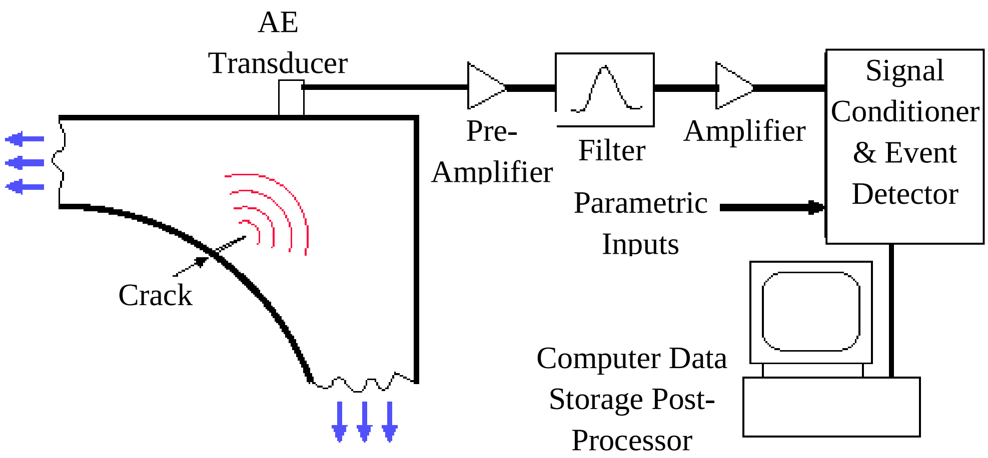

Figure 2.8: A typical AE system setup

Source: Huang et al (1998)

2.3.5 Acoustic Emission's Sensor

Acoustic emission's sensors react with dynamic movement which is caused by an AE wave. As in figure 2.9, the transducer element in an AE sensor is almost always a piezoelectric crystal, which is commonly made from a ceramic such as lead zirconate titanate (PZT). Transducers which convert mechanical movement into an electrical voltage signal. In an AE sensor it almost always use piezoelectric crystal, which is usually made from a ceramic like lead zirconate titanate (PZT). (Anastos et al, 2001)

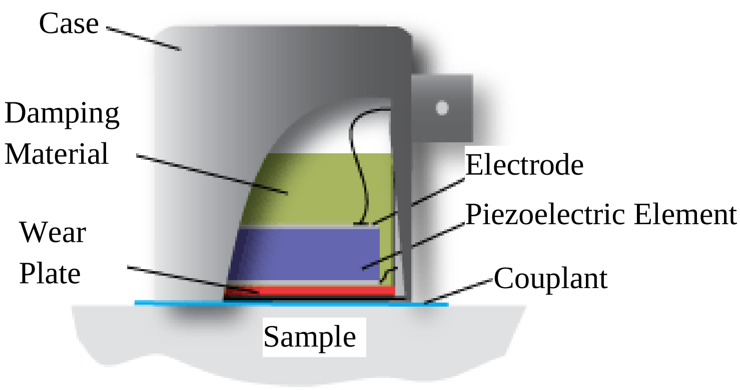

Figure 2.9: View of Acoustic Emission's Transducer.

Source: Anastos et al (2001)

An acoustic emission's will detect the mechanical movement of the material as an electrical signal. But, the signal produced by sensor has small value. Thus, this electrical signal will magnified by using pre-amplifier. So this pre-amplifier will boost the small sensor signal in order to transfer through long signal cable. To minimize the interference, a pre-amplifier was put close to the transducer. Nowadays, many transducers are equipped with integrated preamplifiers.

Filter was divided into three types, low pass, band pass and high pass filter. Filter plays an important role in allowing the amplified signal from sensor and attenuating unwanted noise. Filter with flat frequency response for desired frequencies and sharp cut off for unwanted noise is required. Typical low pass, band pass or high pass can be used. (Huang et al, 1998)

2.3.6 Signal Processing

Typically, the type of signal that being used by using analog to digital converter (A/D), which an analog signal could be converting into digital signal. Meanwhile, digital signal also can be convert into analog signal by using a digital to analog (D/A) converter. These two types of signal can go through the suitable system either analog signal processing or digital signal processing. The signal can be identified due to its categorization such as multi channel and multi dimensional, continuous and discrete time and value. (Proakis and Manolakis, 1996)

Nowadays, the equipment for detecting the leak at pipelines is by using two or multiple sensor. Usually, there was difference time to receive the signal according to sensor's location. So, the leak can be detected due to the time differences for receiving the signal. Thus, these signals will be sending to a processor to identify the location of leak.

The signal sensed by sensor will be analysis to get as much knowledge as possible. There was several type of analysis like time domain, frequency domain, amplitude domain and phase domain. While sensing, there have some distraction on the signal sensed. The distraction may become as nature of acoustic emission radiated from the leak, attenuation between the leak or background noise. (Heubler, 2000)

Location of crack can be determined if the properties of the acoustics' wave is known. Some sort of filter needed to be used to eliminate the unnecessary wave that may be included during wave propagation. The filter needs to be between the crack's location and the sensor itself. Otherwise, the filter cannot eliminate the unintended waves that received by sensor. When, sensor can detect the identified waves, the crack can be determined due to the acoustics' velocity that propagates through the pipeline. (Seaford, 1994)

2.3.7 Acoustic Emission Location Techniques

The main goal of acoustic emission sensing is to find its source's location. AE systems with many channels are capable of recording a hit from a single AE event. AE source can be located if the velocity of the wave and the difference of time arrival at sensors is determined.

2.3.7.1 Linear Location Technique

This method usually uses to evaluate struts on truss bridges. In figure 2.10, when the source of acoustic emission was place between two sensors, then the difference of time arrival for wave will be measured. Distance of the source location from the midpoint will be determined by the arrival time is multiplied by the wave velocity. (Anastos et al, 2001)

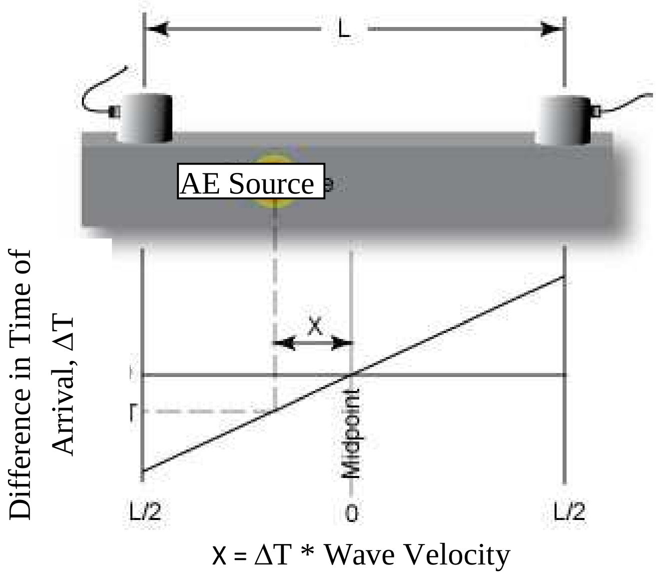

Figure 2.10: Illustration of Linear Location Technique

Source: Anastos et al (2001)

2.3.7.2 Point Location

In figure 2.11, In order for point location to be justified, signals must be detected in a minimum number of sensors. Two sensors will be needed for linear inspection, three sensors for planar and four sensors to justify defect at volumetric level. Accurate arrival times must also be available. Arrival times are often found by using peak amplitude or the first threshold crossing. The velocity of wave propagation and exact position of the sensors are necessary criteria as well. Equations can then be derived using sensor array geometry or more complex algebra to locate more specific points of interest.

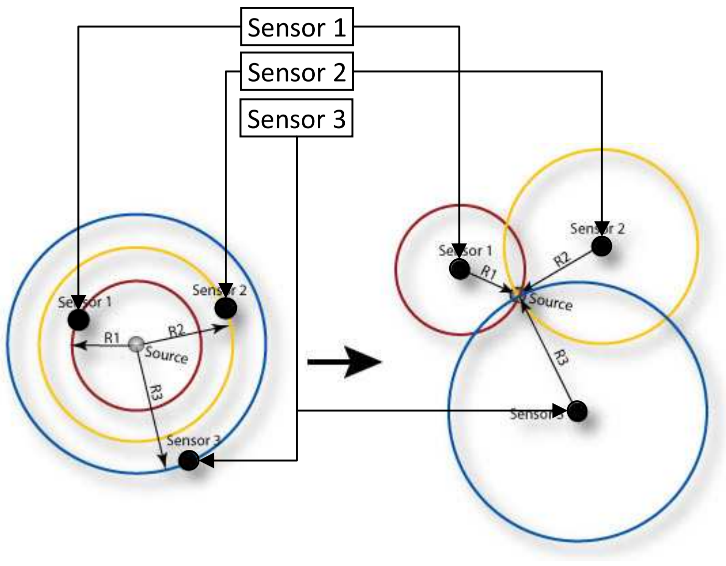

Figure 2.11: Point Location

Source: Anastos et al (2001)

2.3.8 Advantage of Acoustic Emission

These days, acoustic emission technique has found as an effective method that can be used to study the plastic deformation or fracture behavior for different material. The application of this technique was carry out by scientists and engineers into industry. This technique can be used to monitor welding, detect flaw in a large structure at proof testing at surveillance of equipment in operation.

Practically, the application of acoustic emission has already started. The most significant purpose is inspection during the pressure test of large pressure vessels. The objective is to find the presence, location and severity of defects which may propagate under stress. In pressure vessel, acoustic emission is measured when the pressure test are performed. This method to make sure the pipe is safe.

Compared to the others non-destructive technique's method, acoustic emission is a passive method. Passive method means that put several sensors at the structure at suitable interval, then the sensor can detect the signal produced by the defects. Meanwhile, active method the structure needed go through a process like ionizing radiation, ultrasound or magnetic flux.

The acoustic-emission method easily inspects a wide area at a time and also permits inspection of inaccessible, complicated or dangerous areas. The information obtained by the method is entirely different from that obtained by conventional methods. It can clearly detect such defects as tight hair-line cracks that cannot be detected by conventional means. (Watanabe et al, 1976)

2.4 OTHER TECHNIQUES TO INSPECT PIPE LEAK

2.4.1 Visual and Optical Testing (VT)

This is the most basic technique under NDT which is visual examination. Examiners will follow the procedures by simply looking at a part to see if surface imperfections are visible, to using computer controlled camera systems to automatically recognize and measure features of a component. (Anastos et al, 2001)

2.4.2 Thermal Testing

A good material, a good weld or a solid bond will transfer heat quickly through the material. But, defect will keep the heat for longer. Thus, part which is having higher temperature have the defect’s possibility.

Below on figure 2.12 are two images from an IR camera showing a 0.050" thick 7075 aluminum plate sample with a prefabricated crack being inspected using a commercial vibrothermography system. The image on the left is the IR image with a pre-excitation image subtracted. A crack can be seen in the middle of the sample and just to the right of the ultrasonic horn. Also seen is heating due to the horn tip, friction at various clamping sites, and reflection from the hole at the right edge of the sample. The image on the right is the same data with image processing performed to make the crack indication easier to distinguish.

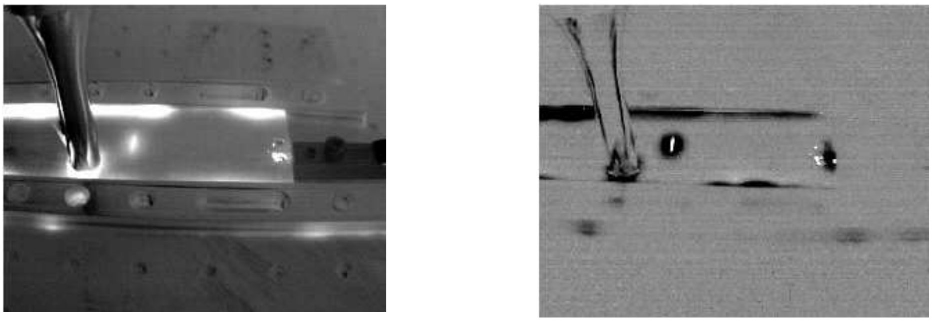

Figure 2.12: Image from Infra Red Camera

Source: Anastos et al (2001)

2.4.3 Eddy Current Testing

When a metal conductor and magnetic line of force crossing each other, it will produce electric current. These electric current are usually refer to as Eddy Current. The process of produce Eddy Current is reversible, which means that from these Eddy current can produce the magnetic lines. This magnetic line also can produce secondary current in the material and this cycle continues. This situation identified as "mutual induction" or "inductive coupling". (Von Flugen, 2000)

In figure 2.13, Note the different signal responses provided by the two probes. The magnetic field that is generated by the eddy currents can be detected using this same probe. We can monitor the magnetic field being produced by these eddy currents with an instrument called an eddy scope. If there is a change in the magnetic field from the eddy currents, we can tell that we have found some sort of defect in the material that we are testing. When the instrument sees a change in the magnetic field generated by the eddy currents, it displays a change in the signal on the screen. (Anastos et al, 2001)

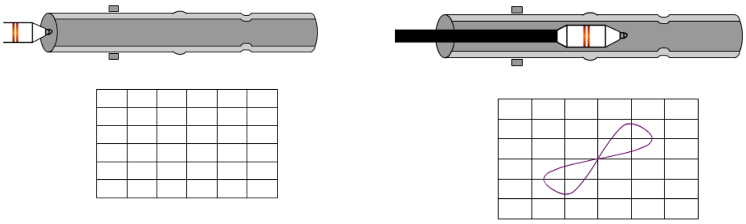

Figure 2.13: Illustration for Eddy Current Testing

Source: Anastos et al (2001)

2.4.4 Radiography

Radiography is a well-established method of NDT having applications in automotive, aerospace, pressure vessel, electronic, and munitions industries, among others. The use of real time radiography (RTR) is increasing due to a reduction in the cost of the equipment and resolution of issues such as the protecting and storing digital images.

This technique produce image electronically rather than on film. Thus, the time taken between the image produced and component tested was very little gap. The electronic image that is produces was the results from the radiation passing through the object being tested and interacting with a screen of material that gives off light when the interaction occurs. (Prosch A. and Larson B., 2000)

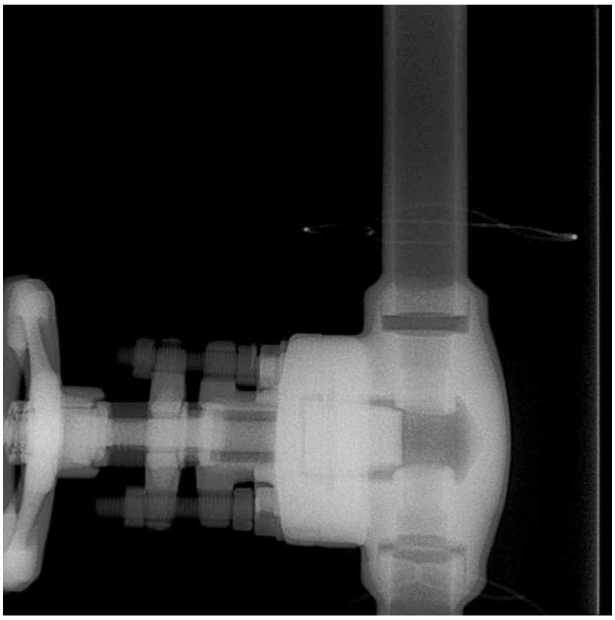

Figure 2.14: Image of pipe valve

Source: Diamond A. (1999)

2.4.5 Magnetic Particle Testing (MT)

Magnetic particle testing is a means of testing iron and steel components for surface and near-surface defects such as cracks, laps and inclusions. It can provide information which makes it possible to avoid premature failures and to correct manufacturing faults such as too harsh grinding. It requires equipment which is comparatively cheap and is capable of testing items as small as a needle or as large as the Queen Mary to a high degree of sensitivity. It will almost certainly produce economies well above the running cost. (King, 1967)

This method is accomplished by inducing a magnetic field in a ferromagnetic material and then dusting the surface with iron particles (either dry or suspended in liquid). Surface and near-surface flaws produce magnetic poles or distort the magnetic field in such a way that the iron particles are attracted and concentrated. This produces a visible indication of defect on the surface of the material. Figure 2.15 demonstrate a component before and after inspection using dry magnetic particles.

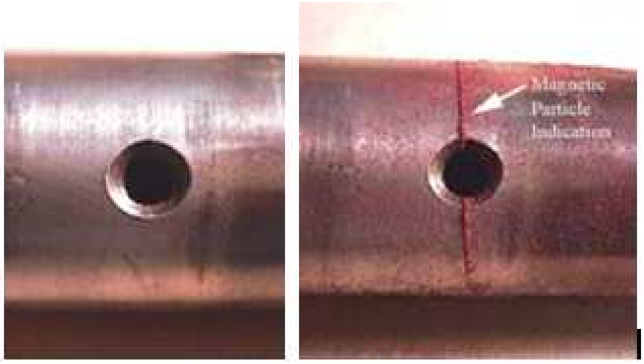

Figure 2.15: Component Before and After Inspection Using Dry Magnetic Particles.

Source: Anastos et al (2001)

2.4.6 Dye Penetrant

This method employs a penetrating liquid, which is applied over the surface of the component and enters the discontinuity or crack. Subsequently, after the excess penetrant has been cleared from the surface, the penetrant exudes or is drawn back out of the crack is observed. Liquid penetrant testing can be applied to any non-porous clean material, metallic or non-metallic, but is unsuitable for dirty or very rough surfaces. Under ultraviolet illumination, non-particulate fluorescent dye penetrants clearly mark the surface traces of fractures in minerals and rocks. The use of fluorescent penetrants has been effective in studying the development of fractures in rock specimens deformed in the laboratory. Fluorescent penetrants are usually used when the maximum flaw sensitivity is required. By using this method, cracks as narrow as 150 nanometers can be detected. (Gardner and Pincus, 1967) Figure 2.16 show the absence of cracks on the other side of the fillet weld was confirmed by the dye-penetrant test,

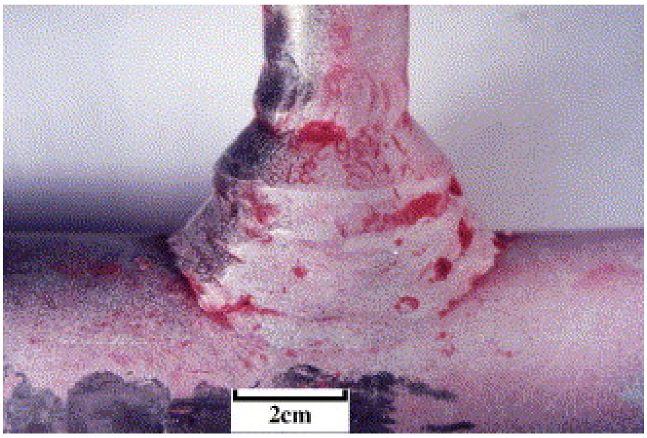

Figure 2.16: Outer surface of fillet weld of non-leaked zone, after dye penetrant test showing smooth contact between weld base and 2-in. (51-mm) pipe.

Source: El-Batahgy and Zaghlou (2005)

2.5 GLOBAL STATISCAL ANALYSIS

The spectral kurtosis (SK) is a statistical tool which can indicate the presence of series of transients and their locations in the frequency domain. As such, it helpfully supplements the classical power spectral density, which as is well known, completely eradicates non-stationary information. (Jeromi Antoni, 2006). In the figure 2,17, it shows how the value of kurtosis can determine the pattern of impulse response wave. Figure 2.17(a) show a signal captured on a faulty rolling element bearing.

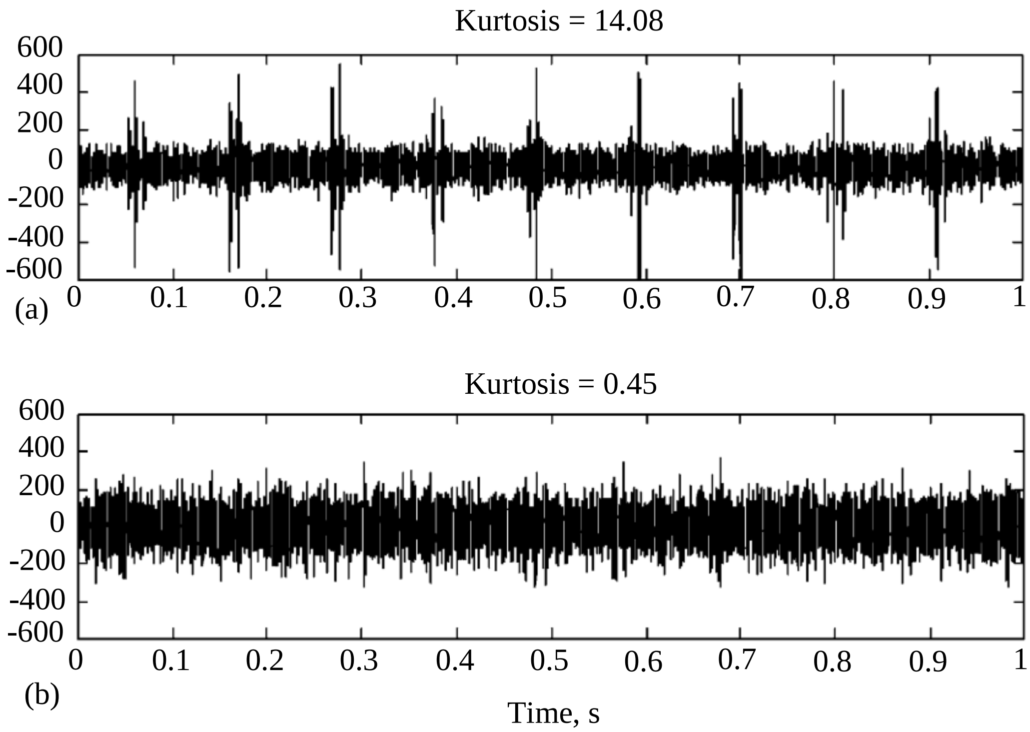

Figure 2.17: Introductory example. (a) A typical vibration signal measured on a system with a faulty rolling element bearing (inner race fault). Note the high kurtosis value. (b) The same vibration signal in the case of a weak ball fault masked by surrounding noise: the kurtosis is almost zero.

Source: Antoni and Randall (2006)

As for the kurtosis, it has two kind of kurtosis depending when it published. The value of kurtosis for normal distribution can be zero or three. It seems both value of kurtosis come at different time. The equation (2.8) is an old-timer equation for Kurtosis, where μ_4 is the fourth moment about the mean and σ is the standard deviation.

$$\beta_2 = \frac{\mu_4}{\sigma^4} \tag{2.8}$$

It said that kurtosis is more commonly defined as the fourth cumulant divided by the square of the second cumulant, which is equal to the fourth moment around the mean divided by the square of the variance of the probability distribution minus 3, which is also known as excess